TRENDS IN ABUNDANCE OF ALASKA HARBOR SEALS, 1983–2001

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ABSTRACT

We estimated trends in abundance of harbor seals (*Phoca vitulina richardsii*) using overdispersed, multinomial models and counts obtained during aerial surveys conducted during 1983–2001 in the Ketchikan, Sitka, Kodiak, and Bristol Bay areas of Alaska. Harbor seal numbers increased significantly at 7.4%/yr during 1983–1998 and 5.6%/yr during 1994–1998 in the Ketchikan area, and 6.6%/yr during 1993–2001 in the Kodiak area. Counts were stable (trends not significant) during 1984–2001 (0.7%/yr) and 1995–2001 (−0.4%/yr) in Sitka, and during 1998–2001 (−1.3%/yr) in Bristol Bay. The influence of covariates (*e.g.*, survey date, tide height) on trend estimates was significant and varied among areas and across years, demonstrating the need to include covariates in statistical analyses to accurately estimate trend. Our increasing trend estimate for Kodiak represents the first documented increase in harbor seal numbers over a relatively expansive area in the Gulf of Alaska. However, the trend for the Gulf of Alaska stock is equivocal due to the continued decline in Prince William Sound. Similarly, the trend for the Southeast Alaska stock is equivocal based on our increasing (Ketchikan) and stable (Sitka) trend estimates, and a recent decline reported for Glacier Bay. The Bering Sea stock appears stable after a period of possible decline.

Key words: aerial surveys, Alaska, covariates, harbor seal, overdispersed multinomial models, *Phoca vitulina richardsii*, stock, trend in abundance, population.

An understanding of population status is a fundamental requisite for the effective management and conservation of marine mammals. Current and accurate

information on trends in abundance is needed also to understand ecosystem dynamics, potential interactions between marine mammals and fisheries, impacts of global climate change on marine mammals, and to measure anthropogenic impacts on the environment (Lowry and Frost 1985, Alverson 1992, Tynan and DeMaster 1997, Anderson and Piatt 1999, Frost *et al.* 1999, Stirling *et al.* 1999, Thompson *et al.* 2001).

The substantial decline in numbers of harbor seals (*Phoca vitulina richardsi*), Steller sea lions (*Eumetopias jubatus*), and northern fur seals (*Callorhinus ursinus*) in the Gulf of Alaska and Bering Sea during the last three decades is reason for concern, especially because the causes of the declines are unknown (NRC 1996). Understanding the declines of these three species is complicated further by the paucity of data on the magnitude and frequency of their natural population fluctuations. For harbor seals in particular, information on trends in abundance over their extensive geographic range in the Gulf of Alaska and Bering Sea is very limited.

In Alaska, harbor seals inhabit coastal waters throughout Southeast Alaska, west through the Gulf of Alaska and Aleutian Islands, and throughout Bristol Bay in the Bering Sea. Obtaining accurate trend estimates across their extensive geographic range would require enormous survey effort. The Alaska Department of Fish and Game (ADF&G) thus established aerial survey routes in smaller regions to provide an index of trends in abundance in the Ketchikan (1983) and Sitka (1984) areas of Southeast Alaska, in Prince William Sound (1984), along the east side of the Kodiak Archipelago (1993), and in southern Bristol Bay (1998) (Fig. 1–5). The National Park Service established a trend route in Glacier Bay (Fig. 1) in 1992. Additionally, counts of seals obtained through land-based studies have provided information on trends in abundance at large individual haul-out sites on Tugidak Island (Fig. 4; #28) (Pitcher 1990), Nanvak Bay in northwest Bristol Bay,[1] and John Hopkins[2] and Muir inlets in Glacier Bay (Calambokidis *et al.* 1987).

The declining trend for the Gulf of Alaska stock is based on the 63% decline in Prince William Sound during 1984–1997 reported by Frost *et al.* (1999), and the 85% decline on Tugidak Island during 1976–1988 observed by Pitcher (1990). Trends in abundance for the Southeast Alaska stock have been based on unpublished reports of counts collected during the 1980s and 1990s from systematic surveys following standardized methodology, whereas for the Bering Sea stock a reliable trend estimate is not available although numerous counts were obtained from surveys conducted since the mid-1960s.[3]

Here we present estimates of trends in harbor seal abundance in the Ketchikan, Sitka, Kodiak, and Bristol Bay areas of Alaska, based on counts obtained during aerial surveys. Our analyses incorporate covariates (*e.g.*, survey date, time relative to low tide) in statistical models to increase accuracy of trend estimates, because environmental and survey-related factors affect haul-out patterns and thus trend estimates based on count data for marine mammals in general (*e.g.*, Garrott *et al.*

[1] Personal communication from L. Jemison, Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, Alaska 99518, U.S.A., September 2002.

[2] Mathews, E. A., and G. W. Pendleton. 2000. Declining trends in harbor seal (*Phoca vitulina richardsi*) numbers at glacial ice and terrestrial haulouts in Glacier Bay National Park, 1992–1998. 24 pp. Available from Glacier Bay National Park, P. O. Box 140, Gustavus, Alaska, 99826, U.S.A.

[3] Hoover-Miller, A. A. 1994. Harbor seal (*Phoca vitulina*) biology and management in Alaska. Report to U.S. Marine Mammal Commission, Contract Number T75134749. 45 pp. Available from the Marine Mammal Commission, 4340 East-West Highway, Room 905, Bethesda, Maryland 20814.
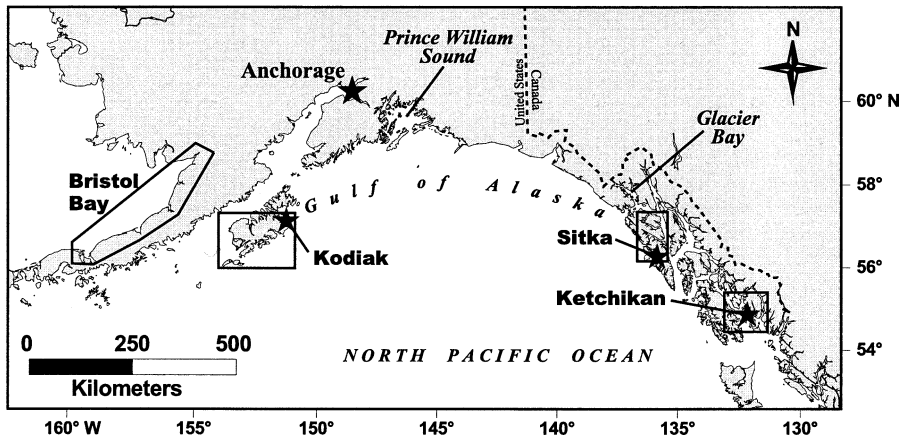
Figure 1. Location of harbor seal population trend routes in the Ketchikan, Sitka, Kodiak, and Bristol Bay areas of Alaska.

1994, Eberhardt *et al.* 1999, Forney 2000) and harbor seals in particular (Thompson and Harwood 1990, Frost *et al.* 1999, Olesiuk 1999, Ver Hoef and Frost, in press).

METHODS

Aerial Surveys

The Ketchikan (Fig. 2) and Sitka (Fig. 3) aerial trend routes were first surveyed in 1983 and 1984 (Pitcher, unpublished data), followed by only one additional survey of the Ketchikan route in 1988 (Pitcher, unpublished data) prior to consecutive annual surveys beginning in 1994 for Ketchikan and 1995 for Sitka. Beginning in 1998, ADF&G surveyed the Ketchikan route biennially due to low variation associated with an estimated long-term increasing trend (Small, unpublished data). The Kodiak (Fig. 4) and Bristol Bay (Fig. 5) trend routes were established in 1993 and 1998, respectively, and surveyed annually through 2001. Haul-out sites within the Ketchikan and Sitka routes were selected primarily because they represented the large majority of sites within a logical flight sequence and could be surveyed within approximately 4 h from an airport; sites with few (<5) seals were not included. For the Kodiak and Bristol Bay routes, all haul-out sites along a relatively extensive coastline were selected. Specifically, all sites on the east side of Kodiak Island from Chiniak Bay (near Kodiak) south to Tugidak Island were included in the Kodiak route, whereas in Bristol Bay all sites between Kvichak Bay and Port Moller on the north side of the Alaska Peninsula were included. The sites within Herendeen Bay and the southeast arm of Port Moller were not included in the Bristol Bay route because the number of seals using those sites was relatively much smaller compared to sites nearer the open waters of Bristol Bay, and their inclusion would increase the duration of the survey substantially.

Each trend route consisted of 16–34 harbor seal haul-out sites that were surveyed with either single- or twin-engine aircraft during the molting period between mid-August and early September. Surveys usually were conducted between 2 h either
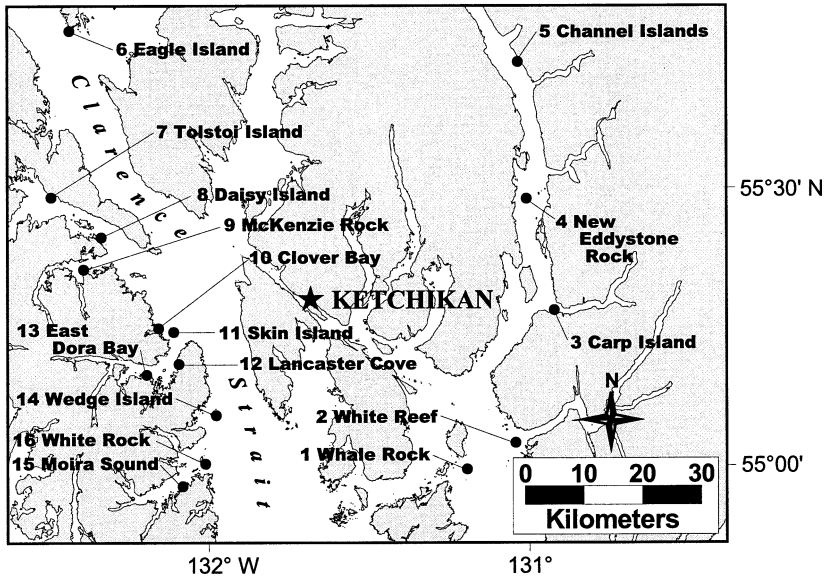
Figure 2. Location of the 16 haul-out sites where counts of harbor seals were obtained during aerial surveys during 1983–1998 to estimate population trend near Ketchikan, Alaska.

side of the low tide, at an altitude of 200–300 m unless weather conditions required lower altitudes; surveys were not conducted during heavy rain or strong winds. After locating hauled-out seals, the pilots circled the site and the observer visually counted all seals (including those in the water near haul-outs), using binoculars when necessary, and then photographed sites using either 35-mm color slide film (ASA 400) or digital images and a 80–200-mm zoom lens for groups of >10–15 seals. We recorded the time when seals at each site were counted, so that tide height at each site during the survey could later be estimated based on tide data from the nearest tide station. Survey times were not recorded for the 1983 Sitka survey, and therefore those counts are not included in our analysis. We attempted to conduct five to seven replicate surveys per year for each route, with each site surveyed unless prohibited by poor weather. Seals were later counted from projected slide images on a white surface or from a computer monitor for digital images. The replicate counts for each trend site were reported previously (Small, unpublished data).

Trend Analysis

   An estimate of population trend based on counts must account for the variation in those counts that results from both real changes in population abundance and factors that affect the proportion of the population visible during surveys. Rather than assume that a constant proportion of seals was visible, and thus observed, during each survey we modeled counts as a function of both covariates that we assume affected visibility (*e.g.*, survey date, time of day) and a polynomial function of year that we assume reflected population changes (*i.e.*, trajectory). We estimated the relationships between counts and these explanatory variables using generalized
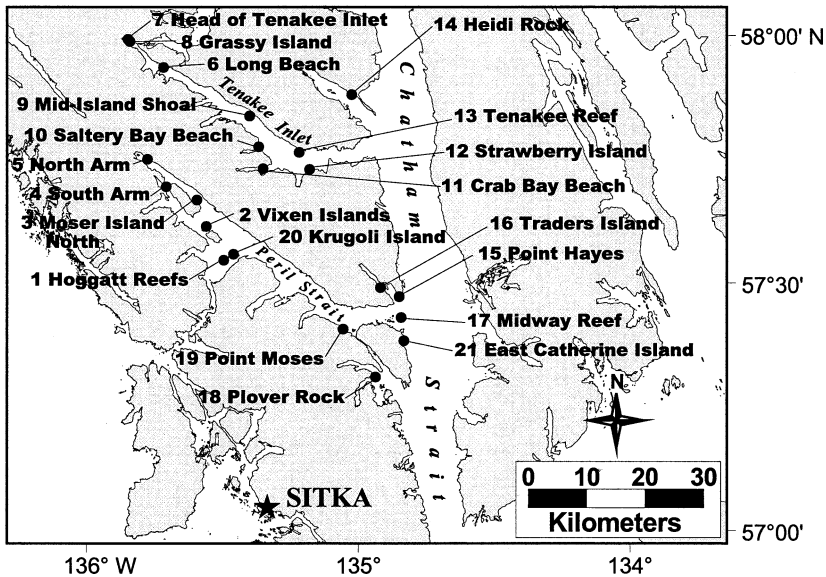
Figure 3.   Location of the 21 haul-out sites where counts of harbor seals were obtained during aerial surveys during 1984–2001 to estimate population trend north of Sitka, Alaska.

linear models following the method described by Link and Sauer (1997), extended to include continuous covariates. The population trajectory can be thought of as a smoothed curve proportional to the actual population size across years. Because trajectories are not always linear (*i.e.*, the rate of change varies through time) on the log scale, we defined population trend (*i.e.*, lambda, finite rate of increase) as the geometric mean rate of change over the interval of interest. Trend is therefore a single-number summary of the average change in the trajectory.

We used four covariates in our analyses: survey date, time to solar midday, time to low tide, and tide height at each site when surveyed. In addition, we included quadratic terms for each of these covariates (*e.g.*, date^2) and allowed the effect of tide height to vary by site (*i.e.*, site × tide height interaction). The two tide variables we used, time to low tide and tide height, potentially measured different aspects of tide influence on seal counts. Specifically, tide height at the time a count is obtained could affect the number of seals hauled out because the space available at many survey sites is directly related to tide height. Additionally, because of daily variation in the height of low tide at the same site, the amount of available haul-out substrate could differ substantially, even at the same stage of the tide (*i.e.*, low tide). We included time to low tide as a covariate because previous studies have found that the number of seals hauled out can be influenced substantially by the time relative to low tide, independent of the low tide height (Olesiuk 1999; Ver Hoef and Frost, in press).

The analyses we used to estimate trends differs somewhat from the methods of Ver Hoef and Frost (in press). Poisson regression models are used in both analyses with the same covariates, although Ver Hoef and Frost (in press) use the height of the low tide rather than tide height when counts are obtained. The principle differences are that we used a generalized linear model (Link and Sauer 1997) *versus*
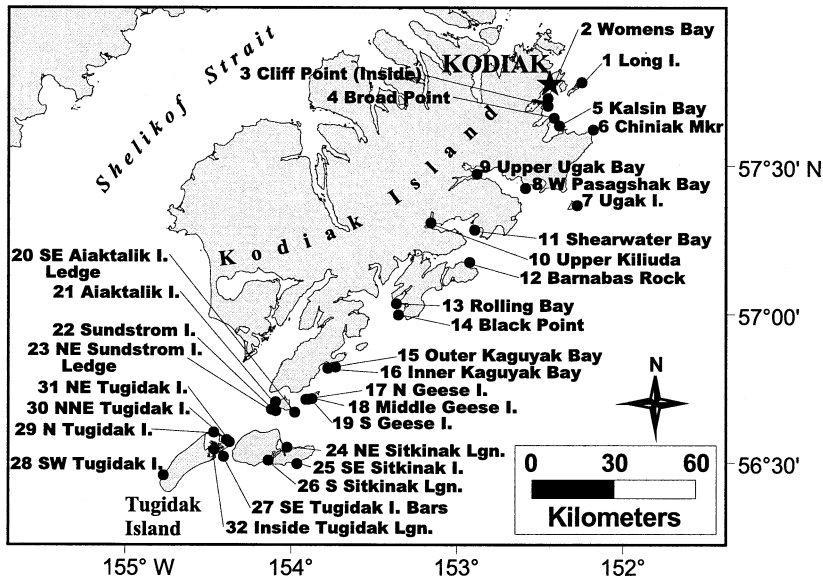
Figure 4. Location of the 32 haul-out sites where counts of harbor seals were obtained during aerial surveys during 1993–2001 to estimate population trend for Kodiak Island, Alaska.

their use of Bayesian hierarchical methods. In addition, Ver Hoef and Frost (in press) used more complex covariate models, by estimating separate site-specific covariate and trend effects that were then combined in the Bayesian hierarchical framework to estimate region-wide covariate effects and trends. We computed region-wide estimates only for trend and for covariates other than the effect of tide height. We believe the effect of tide on the number of seals hauled out more likely varied among survey sites because of the sites' physical structure than would the effect of the other covariates. Variation in counts due to site-specific variation in covariate effects (other than tide) became part of the site-specific overdispersion parameters we estimated or part of the residual variance.

We fit all combinations of covariates and both linear and quadratic population trajectories (*i.e.*, change in counts across years on the log scale) for a total of 768 models. Final trend estimates and standard errors were obtained as a weighted average of trend estimates from the individual models with weights based on corrected Akaike's Information Criteria (AICc) (Hurvich and Tsai 1989, Burnham *et al.* 1995). This model-averaging procedure (Burnham and Anderson 1998) incorporates the uncertainty in choice of model into the estimate and its variance. Approximate 95% confidence intervals for trend estimates were computed as the weighted estimate $\pm 1.96 \times$ weighted standard error. A trend estimate was considered statistically significant when the associated confidence interval did not include zero.

We calculated an adjusted index of population size by fitting a year-effects model. In this model, year was fit as a categorical variable after adjusting for the weighted average covariates from the model averaging. This results in an estimate of abundance for each year relative to the other years. Because the proportion of the
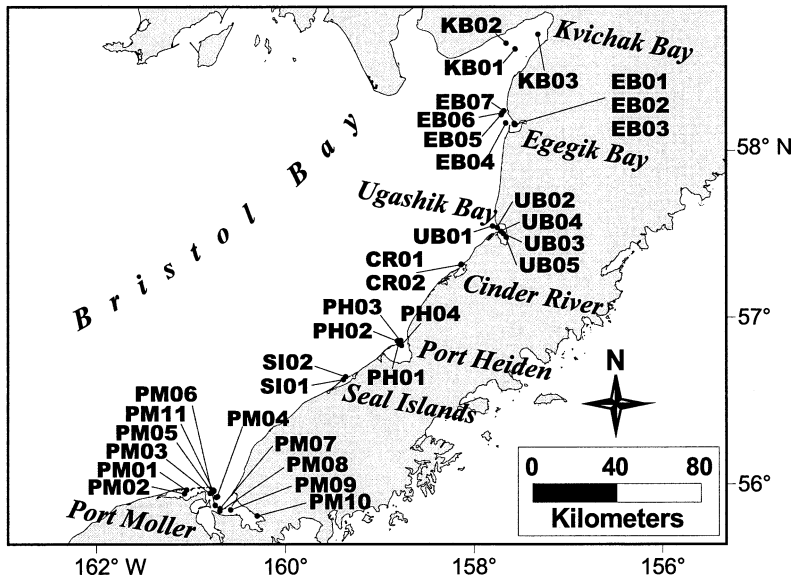
Figure 5. Location of the 34 haul-out sites where counts of harbor seals were obtained during aerial surveys during 1998–2001 to estimate population trend for Bristol Bay, Alaska.

population counted cannot be determined without additional data, estimated trajectories and adjusted indices were scaled to an arbitrary level. This level was usually based on the count in the mid-year of the dataset, or, when there was an even number of years, the average of the adjusted counts in the two middle years. When there were gaps in the data, adjustments were made to the year with data closest to the mid-year of the sequence.

We calculated an importance index for each covariate following the procedure suggested by Burnham and Anderson (1998:140–141). For each covariate, the index is the sum of the model weights for all models that include that covariate. The index takes on values from 0 to 1 with higher values indicating more important covariates. In addition to the importance index, we calculated the sensitivity of the trend estimate to the use of the covariates. Specifically, we examined sensitivity by computing model-averaged trend estimates from subsets of the models not containing individual covariates (*e.g.*, all models without time and date^2). We then calculated the percent change in model-averaged trend by comparing the estimate from the subset with the estimate from the full set of models.

RESULTS

Based on counts obtained during the 15-yr period between 1983 and 1998 (Table 1), harbor seal numbers in the Ketchikan survey area exhibited a significant increase of 7.4%/yr (Table 2; Fig. 6). A slightly lower significant increase of 5.6%/yr was estimated for 1994–1998 (Fig. 7). No significant trends were detected in counts from the Sitka area from 1984 to 2001 (0.7%/yr) or from 1995 to 2001 (−0.4%/yr) (Table 2, Fig. 6, 7). A significant increase of 6.6%/yr in counts was

Table 1. Annual mean counts of harbor seals from population trend routes in the Ketchikan, Sitka, Kodiak, and Bristol Bay areas of Alaska, 1983–2001. An adjusted index for each count was calculated after adjusting for the covariates present in the final model used to estimate population trend and then scaled to the year in the middle of available counts (see text).

Year	Ketchikan		Sitka		Kodiak		Bristol Bay	
	Mean count	Adjusted index	Mean count	Adjusted index	Mean count	Adjusted index	Mean count	Adjusted index
1983	1,059	977	1,169	–	–	–	–	–
1984	1,554	1,168	1,273	1,749	–	–	–	–
1988	1,821	1,625	–	–	–	–	–	–
1993	–	–	–	–	2,522	3,157	–	–
1994	2,228	2,228	–	–	3,172	3,561	–	–
1995	2,604	2,533	2,041	2,041	3,512	4,074	–	–
1996	2,706	2,825	1,602	2,012	2,584	3,430	–	–
1997	–	–	2,183	1,930	3,880	3,880	–	–
1998	3,146	2,832	1,862	1,930	4,339	4,396	10,916	11,192
1999	–	–	2,284	2,076	4,759	4,890	11,169	10,980
2000	–	–	2,222	1,823	4,269	5,092	10,790	10,653
2001	–	–	2,313	1,924	5,385	5,379	11,475	10,629

Table 2. Harbor seal annual population trend estimates (% change/year), associated 95% confidence limits, and cumulative % change for the Ketchikan, Sitka, Kodiak, and Bristol Bay areas of Alaska, 1983–2001.

Area	Years	n^{a}	Trend (SE)	95% Confidence limit	Cumulative % Change
Ketchikan	1983–1998	7 (16)	7.4 (0.66)	6.1–8.7	293.4
Ketchikan	1994–1998	4 (16)	5.6 (1.16)	3.4–7.9	23.9
Sitka	1984–2001	8 (21)	0.7 (0.59)	−0.4–1.9	12.4
Sitka	1995–2001	7 (21)	−0.4 (1.38)	−3.1–2.3	−2.5
Kodiak	1993–2001	9 (32)	6.6 (0.69)	5.3–8.0	67.0
Bristol Bay	1998–2001	4 (34)	−1.3 (2.35)	−5.9–3.3	−3.8

[a] The number of years the route was surveyed and the number of sites within the route (in parentheses) during the period that the population trend was estimated.

detected for the Kodiak survey area from 1993 to 2001 (Table 2; Fig. 7). The trend of −1.3%/yr in Bristol Bay for 1998–2001 was not significant. Covariates substantially influenced population trend estimates for all four survey routes (Table 3) and the relative importance of each covariate varied among the four routes (Table 4). The largest percent change in trend estimates for Ketchikan 1994–1998, Sitka 1984–2001, and Sitka 1995–2001 was observed when survey date was omitted (Table 3), and survey date had maximum importance (*i.e.*, 1.0) for all but the Bristol Bay trend estimate. Relative counts were highest on the earliest recorded survey date for both the Sitka (18 August) and Kodiak (15 August) routes, with counts decreasing approximately 15% and 21% over the next 10 d, respectively (Fig. 8). Relative counts were highest for the Ketchikan route around 22 August, with an approximate 16% decrease 10 d earlier or later, whereas relative counts were nearly constant over the 15-d period (13–28 August) for which counts in Bristol Bay were obtained (Fig. 8). Time to solar midday also influenced population trends substantially, with the Ketchikan 1983–1998 and Kodiak 1993–2001 trend estimates more sensitive to the omission of time to midday than survey date (Table 3), and time to midday^{2} had the highest importance values following survey date (Table 4). Relative counts were highest near midday for Ketchikan, Sitka, and Bristol Bay whereas relative counts were highest approximately one hour after midday for Kodiak (Fig. 9). Time to low tide also influenced trend estimates, particularly for Ketchikan 1994–1998 and Sitka 1995–2001, as did tide height for the Sitka route (both periods), whereas the Bristol Bay trend was most influenced by the omission of the site × tide height interaction (Table 3). The relative importance of these two covariates varied more than survey date and time to midday (Table 4). For Ketchikan, Sitka, and Bristol Bay relative counts were highest near low tide (MLLW; *i.e.*, 0.0 m) whereas counts were highest about one hour before low tide for Kodiak (Fig. 10). Counts decreased gradually on either side of low tide in all areas except Bristol Bay where relative counts decreased more quickly outside of peak low tide (Fig. 10).

Discussion

The 6.6% annual increase in seals counted on the Kodiak trend route during 1993–2001 represents the first documented increase in harbor seal numbers over
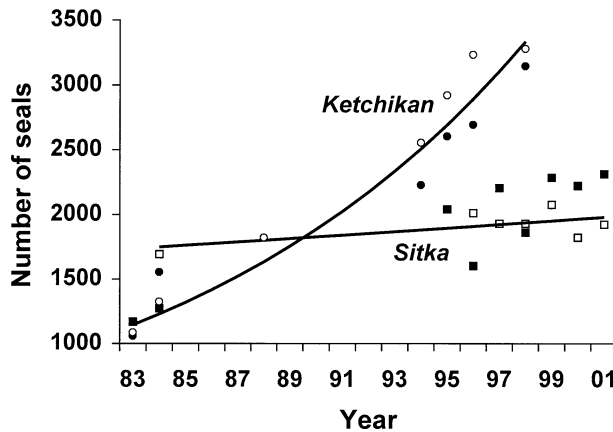
Figure 6. Harbor seal population trajectories for the Ketchikan and Sitka survey areas in Alaska during 1983–2001. Trajectories were based on adjusted indices (open markers) derived from mean annual counts (solid markers) adjusted for covariates.

a relatively expansive geographic area in the Gulf of Alaska. Previously, two substantial population declines had been recorded in the Gulf of Alaska. First, counts decreased approximately 85% from 1976 to 1988 on the Southwest Beach haul-out of Tugidak Island (Fig. 4; #28), a site that formerly had one of the largest concentrations of harbor seals in the world (Pitcher 1990). Pitcher (1990) reported a 21%/yr decline from 1976 to 1978 and a less dramatic decline (7%/yr) from 1978 to 1988. Counts of seals on Tugidak Island stabilized during the late 1980s to early 1990s and increased at 3.0%/yr from 1994 to 2000.[1] Second, a decrease of 63% during 1984–1997 was recorded in eastern and central Prince William Sound (Frost *et al.* 1999). Complete counts of all the haul-out sites that comprise the Kodiak trend route were not conducted until the 1990s; however, maximum counts of seals at five of the larger haul-out sites on the Kodiak trend route were obtained in the mid-1970s (Pitcher and Calkins 1979). A comparison between the mid-1970s counts at these five sites, and maximum counts from the early 1990s at these sites, revealed a mean decline of 66% (range: 35% to 79%),[4] indicating a significant decline occurred throughout the eastern Kodiak Island area prior to the 6.6%/yr increase we observed from 1993 to 2001.

In contrast to a change in harbor seal population trend from a severe decrease to a recent significant increase in the Kodiak region, evidence is lacking for a change in population condition. Harbor seal body condition did not change based on morphometric indices from the mid-1970s through the mid-1990s in the Gulf of Alaska, although sampling limitations reduced the power to detect changes in body condition (Fadely 1997). Gerrodette and DeMaster (1990) reported that knowledge of trends in both abundance and condition indices could be used to deduct changes in carrying capacity. For the Kodiak region, we suggest the apparent stable body condition reported by Fadely (1997) indicates that changes in harbor seal population trend followed similar changes in carrying capacity. Specifically, a sharp
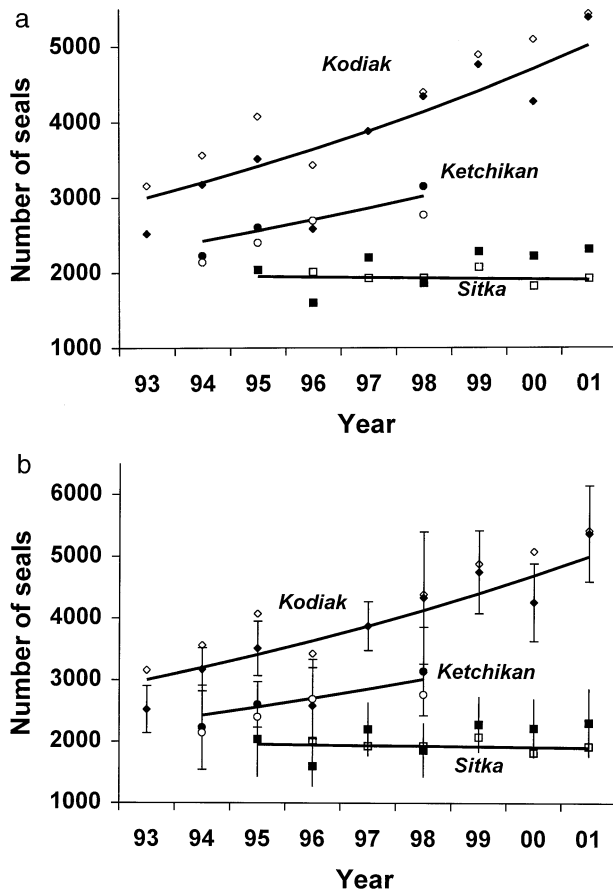
Figure 7.   Harbor seal population trajectories (a) for the Ketchikan, Sitka, and Kodiak areas in Alaska during 1993–2001; (b) 95% confidence intervals for mean counts. Trajectories were based on adjusted indices (open markers) derived from mean annual counts (solid markers) adjusted for covariates.

decrease in carrying capacity from the mid-1970s through the late 1980s, followed by a period of stabilization in the early 1990s.

Covariates substantially influenced the number of harbor seals hauled out at sites within each of our four aerial survey routes, and thus our estimates of population trend. Generally, survey date consistently had the largest influence on trend estimates, followed by a substantial influence due to both time to midday and time to low tide; tide height had the least influence among the covariates we measured. The influence of these covariates was markedly different for the Bristol Bay survey route, where time to low tide and the interaction between individual sites and tide height had a greater influence than either date or time to midday. This result is consistent with the distinctly different haul-out substrate (large flat sandbars) of all the Bristol Bay sites that are available to seals only during a relatively short period surrounding low tide. The relative influence of the covariates varied among the other three routes and for the two time periods for which Ketchikan and Sitka trend

Table 3. Harbor seal annual population trend estimates, and percent change in trend estimates, with the omission[a] of individual environmental covariates for the Ketchikan, Sitka, Kodiak, and Bristol Bay areas of Alaska, 1983–2001.

| Covariate omitted | Ketchikan | | | | Sitka | | | | Kodiak | | Bristol Bay | |
| | 1983–1998 | | 1994–1998 | | 1984–2001 | | 1995–2001 | | 1993–2001 | | 1998–2001 | |
	Trend	%	Trend	%	Trend	%	Trend	%	Trend	%	Trend	%
None (full model)	7.4	–	5.6	–	0.7	–	–0.4	–	6.6	–	–1.3	–
Year²	7	–5.5	5	–11.9	0.8	4.1	–0.4	2.4	6.7	0.5	–	–
Date	7.5	0.8	10	76.9	3.2	336.7	2.2	642.3	7	5.8	–1.3	–3.6
Time to midday	5.7	–22.7	7.1	26	1.1	50.8	0	99.8	7.7	16.4	–1.5	–14.3
Time to low tide	7.1	–4.4	7.3	29.6	0.8	2.9	–1.1	–171.3	6.8	3.2	–1.1	17
Tide height	7.2	–3.3	5.5	–1.2	1.2	68.6	0.4	187.6	6.8	8.1	–1.2	9.6
Site × tide height	7.4	0	5.6	0.3	0.6	–17.6	–0.3	20.5	6.7	0.9	–1.8	–42.2

[a] The linear, quadratic, and interactions (where appropriate) forms of each covariate were omitted, except only the quadratic form of year was omitted.

Table 4. The relative importance of each covariate in the estimation of harbor seal population trends in Alaska; 1.0 indicates maximum importance and 0 is no importance (see methods).

Covariate	Ketchikan		Sitka		Kodiak	Bristol Bay
	1983–1998	1994–1998	1984–2001	1995–2001	1993–2001	1998–2001
$Year^2$	0.921	1.000	0.118	0.326	0.70	–
Date	1.000	1.000	1.000	1.000	1.000	0.227
$Date^2$	0.997	0.998	0.306	0.748	0.073	0.226
Time to midday	0.143	0.808	0.074	0.378	0.817	0.227
Time to midday^2	1.000	1.000	0.958	0.986	0.994	0.651
Time to low tide	1.000	1.000	0.379	0.378	0.885	0.281
Time to low tide^2	0.337	0.594	0.881	0.835	0.797	1.000
Tide height	0.009	0.100	0.000	0.548	0.000	0.000
Tide height^2	0.846	0.999	0.344	0.388	0.444	0.820
Site $\times$ tide height	0.206	0.480	1.000	0.160	1.000	0.999

estimates were based. Using a similar analysis to determine the relative influence of covariates on a harbor seal population trend estimate for Prince William Sound, Frost *et al.* (1999) reported that time of day had the greatest influence, followed by date, and then time to low tide. Ver Hoef and Frost (in press) reported site-specific variation among the trend sites of the Prince William Sound survey route based on a Bayesian hierarchical model. Combined, these results demonstrate that the influence of covariates can vary spatially at the site and regional scale, as well as temporally across years. We believe priority should be placed on determining the relative effects of covariates on trend estimates (*e.g.*, Table 3, 4) rather than attempting to interpret seal haul-out behavior from aerial counts by estimating specific levels of probability and statistical significance of each covariate, following recommendations outlined by Johnson (1999). Further, our study and others (Frost *et al.* 1999; Olesiuk 1999; Ver Hoef and Frost, in press) have documented that the influence of environmental covariates on estimates of population trend is substantial and thus biologically significant. Thus we recommend the integration of covariates in trend analyses to produce more accurate trend estimates required for the management of harbor seals.

Land-based harbor seal counts collected daily throughout the pupping and molting periods over a series of years in Alaska have demonstrated directional shifts in peak counts among years that need to be considered when estimating population trend. For example, maximal counts on Tugidak Island during the molting period were two to four weeks later in the late 1970s than in the late 1990s.[1] In addition, Jemison and Kelly (2001) reported differences in the ratio of the number of seals hauled out during the pupping versus the molting period across decades. Shifts in peak counts among years may indicate haul-out patterns of seals changed in response to shifts in timing of ocean productivity, or changes in prey composition or abundance. These shifts also may result from apparent or true changes in age- and sex-structure, due to differential mortality or haul-out patterns between sexes
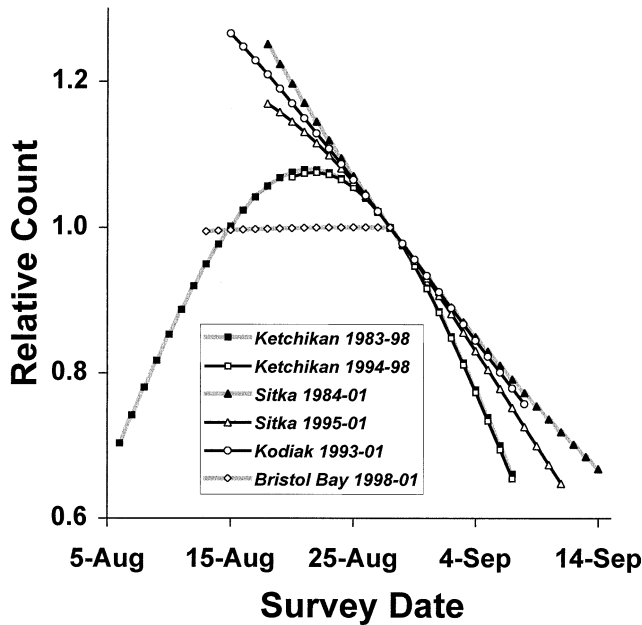
Figure 8. Predicted influence of survey date on the relative counts (equal 1.0 on 28 August) of harbor seals in the Ketchikan, Sitka, Kodiak, and Bristol Bay areas of Alaska, 1983–2001.

and among age-classes (Thompson and Rothery 1987, Härkönen *et al.* 1999), because timing of molt appears to vary predictably among sexes and age-classes for Alaska harbor seals (Daniel *et al.* 2003). Shifts in peak counts and changes in age/ sex structure can potentially decrease precision and introduce bias in population trend estimates (Härkönen *et al.* 1999). We believe inclusion of date, as a covariate, in our analysis accounts for the age- and sex-specific haul-out patterns, if the age- and sex-structure remains relatively stable (Härkönen *et al.* 1999); the temporal and spatial variation in age- and sex-structure for our survey periods is unknown.

To examine additional concerns, the design of Alaska harbor seal population surveys was investigated by employing an operating-model approach to simulate harbor seal population dynamics and haul-out behavior that incorporated numerous factors that potentially affect trend estimates generated from aerial survey data.[5] Generally, simulation results indicated that covariate-corrected trend estimates are robust, including those based on surveys conducted up to 20 d on either side of the actual peak in the number of seals hauled out during the molt period and surveys that are conducted progressively earlier (or later) across years within the molt period. Linear variation across years in an unknown or "lurking" covariate (*e.g.*, the proportion of time seals haul out during the molt period due to changes in age- and sex-structure) resulted in substantial bias, whereas random variation did not reduce trend estimate accuracy.[5] We believe we have accounted for all known factors that could substantially influence the number of seals counted during aerial surveys, and

[5] Personal communication from M. Adkison, JCSFOS, University of Alaska Fairbanks, 11120 Glacier Hwy, Juneau, Alaska 99801, U.S.A., September, 2002.
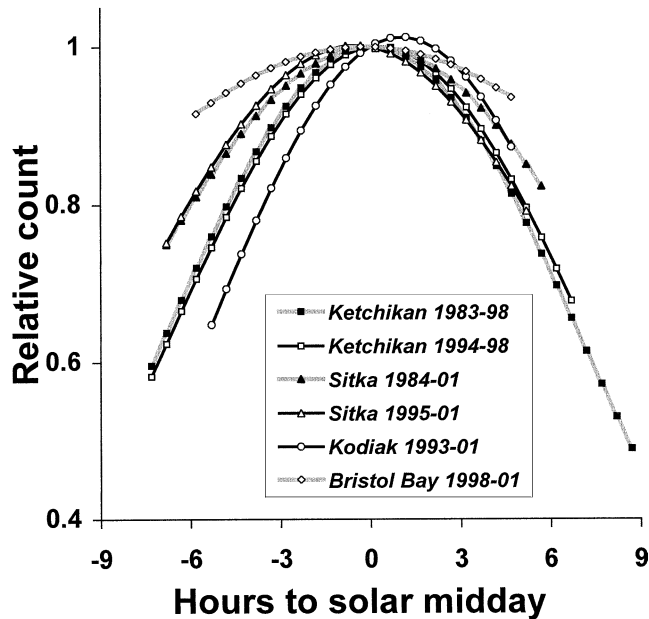
Figure 9.   Predicted influence of hours to solar midday (equal 1.0 at 0 h) on the relative counts of harbor seals in the Ketchikan, Sitka, Kodiak, and Bristol Bay areas of Alaska, 1983–2001.

thus believe our estimates of trends in abundance of Alaska harbor seals are as accurate as possible. Our trend estimates may be more indicative of trends in adult rather than subadult seals if the majority of counts were obtained later in the molt period when the probability of hauling out appears higher for older seals (Härkönen *et al.* 1999, Daniel *et al.* 2003); yet, the timing of the molt period in the different trend route areas is not known. We recognize the need to continue examining how harbor seal behavior and demography may influence trend estimates, and to determine how survey design and data analysis can be modified to account for these effects.

Our results, when combined with those from Prince William Sound (Frost *et al.* 1999; Ver Hoef and Frost, in press) and Glacier Bay,[2] represent the most current information on trends in abundance of Alaska harbor seals that cover relatively large geographic areas based on aerial surveys. These estimates indicate that the trend for the Gulf of Alaska and Southeast Alaska stocks of harbor seals, as currently delineated (Angliss *et al.* 2001), is complex. Specifically, significantly increasing (Kodiak) and decreasing (Prince William Sound) trends were reported during the 1990s in the Gulf of Alaska stock, where the abundance of harbor seals remains substantially (65%–85%) reduced since the early 1970s and 1980s. Within the Southeast Alaska stock during the 1990s, trends were increasing (Ketchikan), stable (Sitka), and decreasing (Glacier Bay). We believe that movement was not a substantial factor driving trends because location data from satellite-tagged harbor seals from Prince William Sound, Kodiak, and Southeast Alaska (Lowry *et al.* 2001; Small, unpublished data), collected concurrently with trend count data, indicated that similar to other harbor seal studies (Suryan and Harvey 1998,
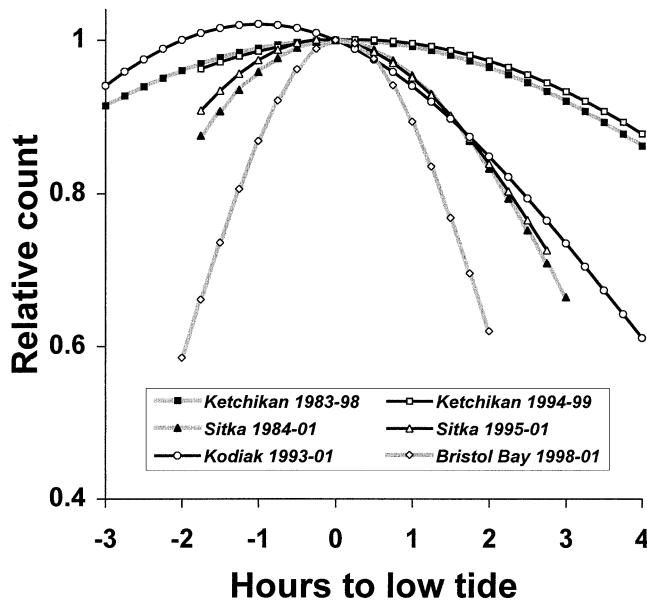
Figure 10. Predicted influence of hours to low tide (equal 1.0 on 0 hours) on the relative counts of harbor seals in the Ketchikan, Sitka, Kodiak, and Bristol Bay areas of Alaska, 1983–2001.

Thompson 1993, Härkönen and Hårding 2001), Alaska harbor seals display relatively strong site fidelity, especially among adults. Although subadults exhibited farther movements than adults, the range of movements for both cohorts do not suggest that a substantial portion of seals moved out of the trend survey areas. For example, none of the 29 seals tagged in the Kodiak Archipelago crossed the Shelikof Strait or traveled north to the Kenai Peninsula or Prince William Sound. We recognize that the short-term nature (*i.e.,* <1 yr) of movements recorded by satellite tags does not provide the definitive movement information needed to determine long-term movement and dispersal patterns. On a finer spatial scale, the potential for the redistribution of seals to result in substantial changes in abundance for a specific trend route will be proportional to the probability that immigration is not equal to emigration among the trend route sites, a probability proportional to the spatial extent of the trend route.

The current population status for the remaining harbor seal stock in Alaska (the Bering Sea stock) appears stable based on our population trend estimate (-1.3%/yr; not significant) from four annual counts (1998–2001). Additional annual counts collected over the next several years will likely decrease variability and provide a more precise trend estimate, yet sympatry with spotted seals (*Phoca largha*), which cannot be distinguished from harbor seals during aerial surveys, will increase the uncertainty in interpreting the trend estimate. Withrow and Loughlin (1996) reported a 3.5%/yr decline between 1975 and 1995 along the north side of the Alaska Peninsula, based on counts collected during the pupping period in 1975–1977, 1985, 1990 and during the molting period in 1991 and 1995; their trend estimate was not adjusted for the effects of covariates. Counts at Nanvak Bay, the

largest haul-out site in northern Bristol Bay (~300 seals) and outside of our trend survey route, increased significantly at 2.1%/yr during the molting period from 1990 to 2000; yet, the maximum count during 2000 was approximately 80% lower than the maximum count in 1975.[1]

There is some evidence of a reorganization of the marine community structure in the western Gulf of Alaska following the 1977 climate-regime shift based, in large part, on long-term small-mesh trawl surveys conducted primarily along the east side of the Kodiak Archipelago and the south side of the Alaska Peninsula during 1953–1997 (Anderson and Piatt 1999). A shrimp-dominated crustacean community, primarily pandalid shrimp (*Pandalus sp.*) during the early and mid-1970s, was replaced by a community dominated by gadids (*e.g.*, walleye pollock [*Theragra chalcogramma*] and Pacific cod [*Gadus macrocephalus*]) and flatfish (*e.g.*, flathead sole [*Hippoglossoides elassodon*] and arrowtooth flounder [*Atheresthes stomias*]). This shift in marine community organization was accompanied by a substantial reduction in nearshore forage fish biomass and followed by decreased abundance of several sea bird species and Steller sea lions in addition to harbor seals (Piatt and Anderson 1996). Although these changes are consistent with a decline in the Gulf of Alaska carrying capacity, numbers of harbor seals in the Kodiak region increased during 1993–2001 without evidence of a subsequent reorganization of the marine community, based on the same trawl survey data. However, an increase in carrying capacity during the 1990s can be inferred from an increase in prey biomass to levels comparable to those prior to the decline (Anderson and Piatt 1999) and changes in the timing of pupping and haul-out behavior on Tugidak Island (Jemison and Kelly 2001) that possibly indicate improved nutritional status.

In conclusion, substantial regional differences exist in trends in abundance of Alaska harbor seals, both within and among the three management stocks currently identified. Recent mitochondrial DNA analyses indicate that the spatial structure of genetically isolated populations of Alaska harbor seals is finer scale than previously reported, including differentiation between the Kodiak Archipelago and Prince William Sound, indicating the current stock structure is inappropriate (Westlake and O'Corry-Crowe 2002). Refinement of the biological stock structure will clarify whether contrasting trends in abundance reflect differences in local population dynamics within one stock or separate individual stocks with distinct trends. Additional information on trends in abundance, and genetic variation, across the geographic range of harbor seals in Alaska is needed to determine if current trend routes provide adequate monitoring of status for all biological stocks of harbor seals in Alaska. Specifically, trend estimates are needed for the Western Gulf of Alaska (excluding the east side of the Kodiak Archipelago) and the Aleutian Islands.

Literature Cited

Alverson, D. L. 1992. A review of commercial fisheries and the Steller sea lion (*Eumetopias jubatus*): The conflict arena. Reviews in Aquatic Sciences 6:203–256.

Anderson, P. J., and J. F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series 189:117–123.

Angliss, R. P., D. P. DeMaster and A. L. Lopez. 2001. Alaska marine mammal stock assessments, 2001. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-124. 203 pp.

Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: An information theoretic approach. Springer-Verlag, Berlin.

Burnham, K. P., G. C. White and D. R. Anderson. 1995. Model selection strategy in the analysis of capture-recapture data. Biometrics 51:888–898.

Calambokidis, J., B. L. Taylor, S. D. Carter, G. H. Steiger, P. K. Dawson and L. D. Antrim. 1987. Distribution and haul-out behavior of harbor seals in Glacier Bay, Alaska. Canadian Journal of Zoology 65:1391–1396.

Daniel, R., L. A. Jemison, G. W. Pendleton and S. M. Crowley. 2003. Molting phenology of harbor seals on Tugidak Island, Alaska. Marine Mammal Science 19:128–140.

Eberhardt, L. L., R. A. Garrott and B. L. Becker. 1999. Using trend indices for endangered species. Marine Mammal Science 15:766–785.

Fadely, B. S. 1997. Investigations of harbor seal (*Phoca vitulina*) health status and body condition in the Gulf of Alaska. Ph.D. dissertation, University of Alaska Fairbanks, Fairbanks, AK. 183 pp.

Forney, K. A. 2000. Environmental models of cetacean abundance: reducing uncertainty in population trends. Conservation Biology 14:1271–1286.

Frost, K. J., L. F. Lowry and J. M. Ver Hoef. 1999. Monitoring the trend of harbor seals in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill. Marine Mammal Science 15:494–506.

Garrott, R. A., B. B. Ackerman, J. R. Cary, D. M. Heisey, J. R. Reynolds III and J. R. Wilcox. 1994. Trends in counts of Florida manatees at winter aggregation sites. Journal of Wildlife Management 58:642–654.

Gerrodette, T., and D. P. DeMaster. 1990. Quantitative determination of optimum sustainable population level. Marine Mammal Science 6:1–16.

Härkönen, T., and K. C. Hårding. 2001. Spatial structure of harbour seal populations and the implications thereof. Canadian Journal of Zoology 79:2115–2127.

Härkönen, T., K. C. Hårding and S. Gunnar Lunneryd. 1999. Age- and sex-specific behaviour in harbour seals *Phoca vitulina* leads to biased estimates of vital population parameters. Journal of Applied Ecology 36:825–841.

Hurvich, C. M., and C. Tsai. 1989. Regression and time series model selection in small samples. Biometrika 76:297–307.

Jemison, L. A., and B. P. Kelly. 2001. Pupping phenology and demography of harbor seals (*Phoca vitulina richardsi*) on Tugidak Island, Alaska. Marine Mammal Science 17:585–600.

Johnson, D. H. 1999. The insignificance of statistical significance testing. Journal of Wildlife Management 63:763–772.

LINK, W. A., AND J. R. SAUER. 1997. Estimation of population trajectories from count data. Biometrics 53:488–497.

LOWRY, L. F., AND K. J. FROST. 1985. Biological interactions between marine mammals and commercial fisheries in the Bering Sea. Pages 41–61 *in* J. R. Beddington, R. J. H. Beverton and D. M. Lavigne, eds. Marine mammals and fisheries. George Allen & Unwin, London.

LOWRY, L. F., K. J. FROST, J. M. VER HOEF AND R. A. DELONG. 2001. Movements of satellite-tagged subadult and adult harbor seals in Prince William Sound, Alaska. Marine Mammal Science 17:835–861.

NRC. 1996. The Bering Sea ecosystem. National Research Council, Washington, DC.

OLESIUK, P. F. 1999. An assessment of the status of harbour seals (*Phoca vitulina*) in British Columbia. Canadian Stock Assessment Secretariat Research Document 99/33.

PIATT, J. F., AND P. ANDERSON. 1996. Response of common murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska. American Fisheries Society Symposium 18:720–737.

PITCHER, K. W. 1990. Major decline in number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Marine Mammal Science 6:121–134.

PITCHER, K. W., AND D. G. CALKINS. 1979. Biology of the harbor seal (*Phoca vitulina richardsi*) in the Gulf of Alaska. U.S. Department of Commerce, NOAA, OCSEAP Final Report 19(1983):231–310.

STIRLING, I., N. J. LUNN AND J. IACOZZA. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic 52:294–306.

SURYAN, R. N., AND J. T. HARVEY. 1998. Tracking harbor seals (*Phoca vitulina richardsi*) to determine dive behavior, foraging activity, and haul-out site use. Marine Mammal Science 14:361–372.

THOMPSON, P. M. 1993. Harbour seal movement patterns. Symposium Zoological Society of London 66:225–239.

THOMPSON, P. M., AND J. HARWOOD. 1990. Methods for estimating the population size of common seals, *Phoca vitulina*. Journal of Applied Ecology 27:924–938.

THOMPSON, P. M., AND P. ROTHERY. 1987. Age and sex differences in the timing of the moult in the common seal, *Phoca vitulina*. Journal of Zoology, London 212:597–603.

THOMPSON, P. M., S. VAN PARIS AND K. M. KOVACS. 2001. Local declines in the abundance of harbour seals: implications for the designation and monitoring of protected areas. Journal of Applied Ecology 38:117–125.

TYNAN, C. T., AND D. P. DEMASTER. 1997. Observations and predictions of arctic climatic change: Potential effects of marine mammals. Arctic 50:308–322.

VER HOEF, J. M., AND K. FROST. In press. A Bayesian hierarchical model for monitoring harbor seal changes in Prince William Sound, Alaska. Environmental and Ecological Statistics.

WESTLAKE, R. L., AND G. M. O'CORRY-CROWE. 2002. Marco-geographic structure and patterns of genetics diversity in Pacific harbor seals (*Phoca vitulina*) from Alaska to Japan as revealed by mitochondrial DNA. Journal of Mammalogy 83:1111–1126.

WITHROW, D. E., AND T. R. LOUGHLIN. 1996. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) along the north side of the Alaska Peninsula and Bristol Bay during 1995. Annual report to the MMPA Assessment Program, Office of Protected Resources, NMFS, NOAA, 1335 East-West Highway, Silver Spring, MD 20910.